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LOW VOLTAGE SELF-QUENCHING GEIGER COUNTERS

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NAVAL RESEARCH LABORATORY
COMMODORE H. A. SCHADE, USN, DIRECTOR
WASHINGTON, D.C.

NRL REPORT N-3189

LOW VOLTAGE SELF-QUENCHING GEIGER COUNTERS

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Approved by:

Dr. E. O. Hulbert, Superintendent, Optics Division
Problem No. 37N03-04 October 24, 1947

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ABSTRACT

Counters filled with small percentages of the halogens mixed with the inert gases produced self-quenching counters. The lifetimes of these counters in terms of total counts are apparently unlimited. Several mixtures exhibited thresholds below 250 volts at total pressures ordinarily used in counters. Pulse size, efficiency, and quenching characteristics are similar to those obtained with argon-alcohol Geiger-Mueller counters filled with a ten-percent alcohol mixture to total pressures in excess of 10 cm Hg. The percentages of halogens required to make good counters were about the same as the optimum concentrations reported* for quenching metastable states in the rare gases.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

* F. M. Penning, Physik. 46; 335-348 (1927)

THE ROLE OF HALOGEN ADMIXTURES IN THE OPERATION OF LOW-VOLTAGE SELF-QUENCHING COUNTERS

Electrical discharges in the rare gases are capable of exciting metastable states of relatively high energy and long lifetime. If a foreign gas is introduced, whose ionization potential is about the same or less than the metastable energy of the rare-gas atoms, the metastable atoms can ionize molecules of the admixture on impact. The probability of this transfer of energy is so large, that only a trace of admixture is necessary to markedly reduce the starting voltage of the discharge. Figure 1, after Penning*, illustrates the reduction of the striking voltage obtained by adding traces of argon (ionization potential 15.7 volts) to neon (excitation energy of metastable states, 16.3 volts). A concentration of as little as 10^{-4} percent of argon produces a marked decrease in the striking voltage. This process is more pronounced in Ne-A than in any other mixture thus far observed, but similar results were obtained* when Hg or the halogens were admixed with the neon or argon. The use of such mixtures to produce Geiger counters operating at relatively low voltages has already been briefly reported†‡. In this paper, additional information will be presented concerning the performance of tubes containing neon or argon and halogen admixtures.† Besides exhibiting low-voltage characteristics, these tubes are superior to self-quenching types utilizing polyatomic vapors in that they have apparently unlimited counting life, and are temperature insensitive down to temperatures in the neighborhood of -70°C.

The rare gases, by themselves, are unsuited for use in counters, because their metastable states are so readily excited in the discharge. The metastable atoms are electrically neutral and drift about in the field, but when one diffuses to the cathode the probability of ejecting an electron may be as high as 50 percent. In pure neon, Pateow§ found a measurable current due to electrons ejected by metastables for as long as a second after the interruption of the discharge. Reignition of the counter discharge by this process leads to an unbroken succession of spurious counts. No true counting is possible in pure neon or argon, even with the aid of external quenching

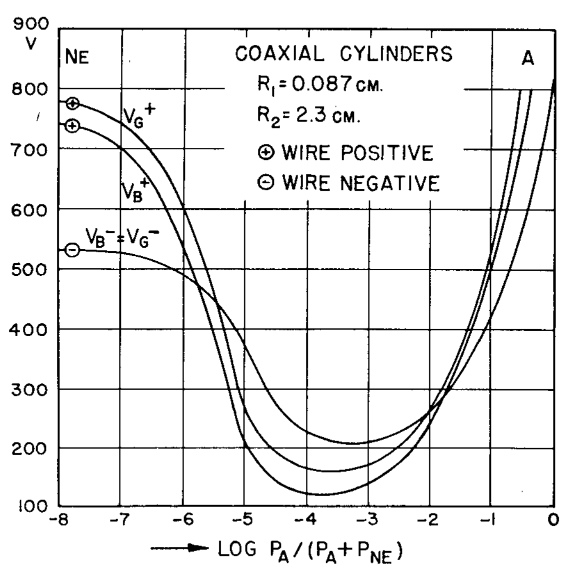

Fig. 1 - Breakdown Potential V_B and Starting Potential of Glow Discharge V_G for Ne-A Mixtures Between Coaxial Cylinders at p_0 = 37.6 MM Reproduced from Ref. (1)
P_A = Percentage A Pressure
PNe = Percentage Ne Pressure

* Penning, F. M., Z. Physik, 46; 335-348 (1927)

† Liebson, S. H., Phys. Rev. 72, 181-182 (1947)

‡ Simpson, Jr., A. J., Phys. Rev. 72, 181 (1947)

§ Paetow, H., Z. Physik, 111; 770-790 (1947)

circuits. It is well known, however, that the admixture of any impurities capable of quenching metastable states, makes counting possible. Admixtures of polyatomic vapors are ordinarily used to obtain self-quenching counters. A proportion commonly used consists of 10 parts of rare-gas pressure to one part of polyatomic-vapor pressure, at a total pressure of about 10 cm. Hg. In most cases a minimum pressure of about 5 mm of the vapor is essential for good counting characteristics. Such counters are limited in counting life due to decomposition of the vapor during the discharge.

Because electron attachment to form negative ions can lead to spurious counts, time lags, and reduced cosmic-ray efficiency, electronegative gases have been steadfastly avoided in counter tubes. Typically enough, if the halogens are used as quenching agents with the rare gases, in the usual 10-percent mixtures, the resulting plateaus are steep and short and the cosmic-ray counting efficiencies are poor. Counting characteristics for an argon-bromine 10-to-1 mixture are shown in Figure 2. At these higher pressures the halogen acts predominantly as an electron trap. If the halogen concentration is reduced, however, ionization of the halogen molecules upon impact with metastable rare-gas atoms soon becomes more probable than electron attachment and the starting voltage is reduced. When the percentage of halogen admixture is in the neighborhood of 0.1 percent, the counters operate at low voltages as fast self-quenching counters with satisfactory plateaus.

Most electrode materials ordinarily used in counter tubes react readily with the halogen vapors. Although the counting properties of freshly prepared tubes appeared to be in no way sensitive to the choice of cathode materials, copper, brass, and silver tubes deteriorated rapidly with age. To minimize loss of the halogen through chemical reaction, experimental tubes were prepared with tantalum cathodes and tungsten anodes. All the data presented below were obtained with tantalum tubes, which have thus far shown no detectable aging. Tubes constructed with carbon or stainless steel electrodes have held up equally well.

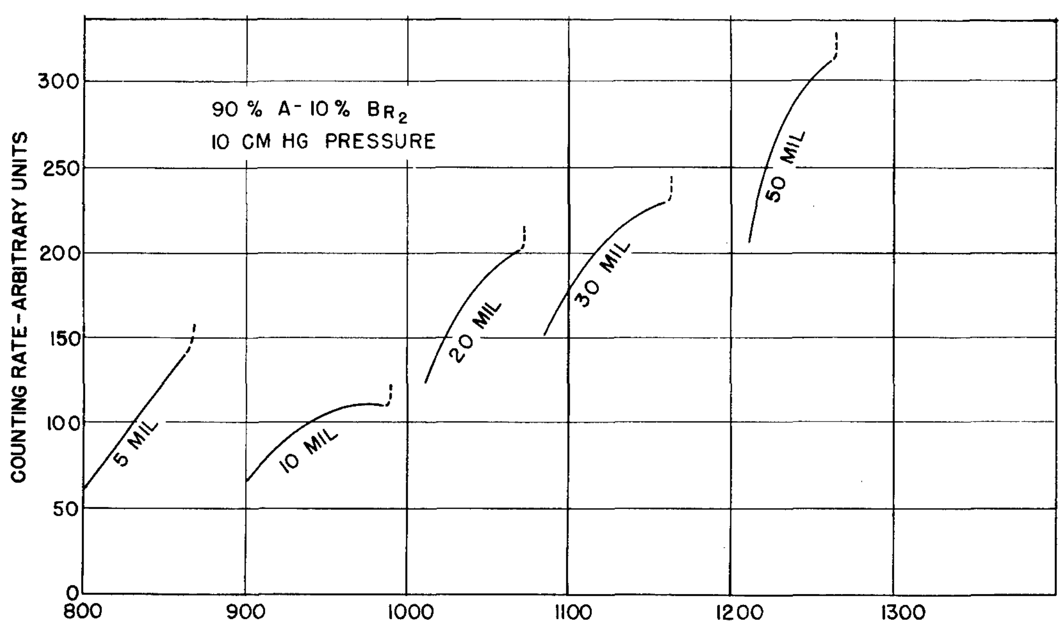

Fig. 2 - Plateaus of Argon-Bromine Mixtures with Different Anode Diameters and Cathode Diameter of 2 cm

The rare gases used in these tubes were of the "spectroscopic" grade of purity. Chlorine was obtained from a "lecture" tank. The bromine was cp grade, distilled several times before use.

THRESHOLD VOLTAGES AND PLATEAUS

Typical curves showing the dependence of threshold on halogen admixture and anode diameter are plotted in Figures 3, 4, 5 and 6. The knees in the curves of Figures 3 and 4 are caused by oscillations which effectively raise the stable threshold voltage. It was observed that as the percentage of halogen decreased, considerable current flowed through the tube before threshold for counting was reached, accompanied by oscillations in the range from 5 to 50 KC per second. These oscillations increased in amplitude as the voltage applied to the counter was raised, until a voltage was reached at which the oscillations ceased. At this point the counting pulse appeared fully developed.

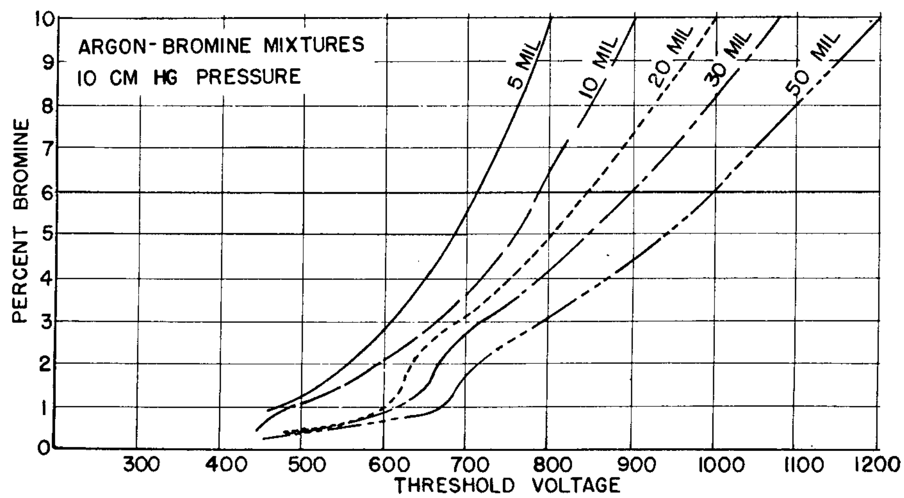

Fig. 3 - Threshold Voltages of Argon-Bromide Mixture with Different Anode Diameters and Cathode Diameter of 2 cm

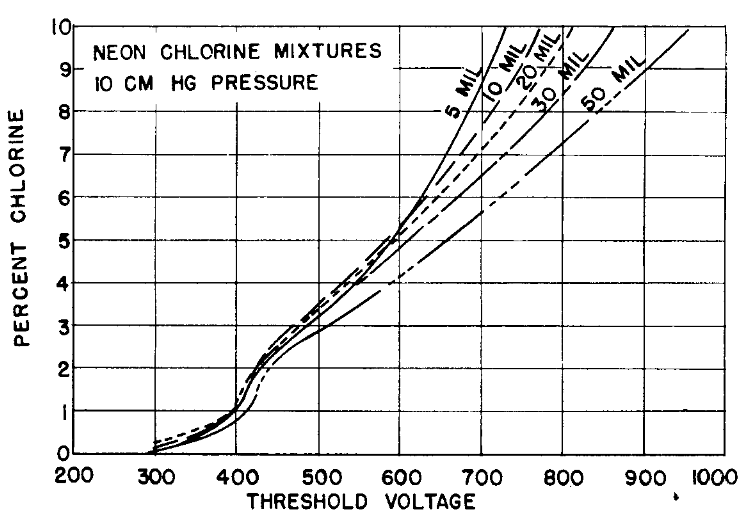

Fig. 4 - Threshold Voltages of Neon-Chlorine Mixtures with Different Anode Diameters and Cathode Diameter of 2 cm

The neon-plus-chlorine or-bromine, and the argon-plus-bromine mixtures have low-voltage characteristics. The argon-chlorine counters operate at higher voltages probably due to the fact that the chlorine ionization potential (13 volts) is higher than the argon metastable energy (11.6 volts).

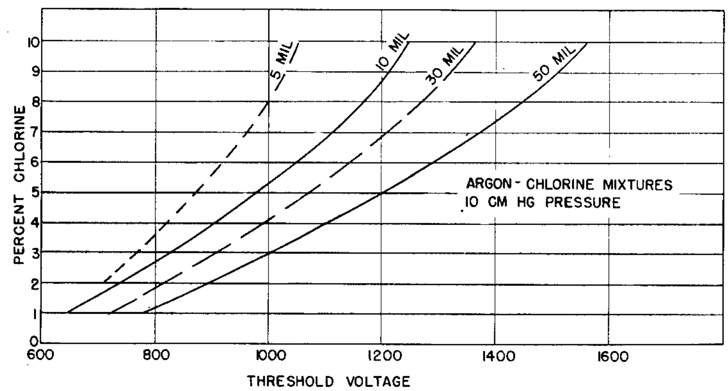

Fig. 3 - Threshold Voltages of Argon-Bromine Mixtures with Different Anode Diameters and Cathode Diameter of 2 cm

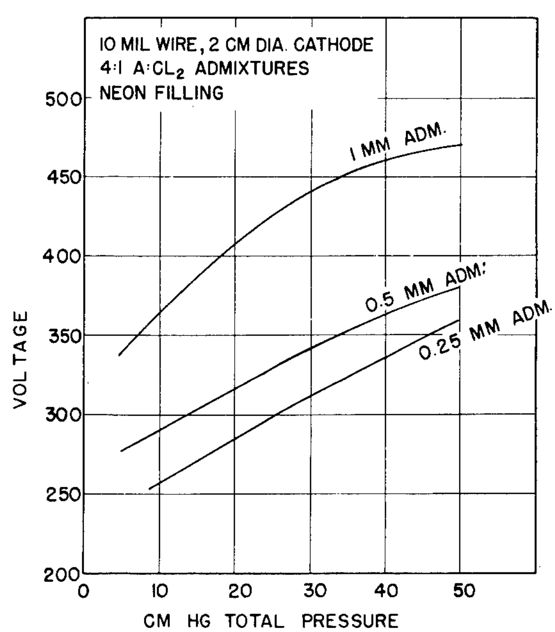

Fig. 4 - Threshold Voltages of Neon-Chlorine Mixtures with Different Anode Diameters and Cathode Diameter of 2 cm

The breakdown voltage of the corona discharge in high-voltage counters is a function of E/p, the ratio of the field strength to the total pressure. In coaxial cylinders, E varies as the logarithm of the ratio of the outer cylinder to the inner one. For the low-voltage counter tubes this functional relationship also holds. For very small halogen concentrations, 400-volt thresholds (about 15 volts plateau) are obtainable with anode diameters of 0.25 inch and a cathode diameter of 1.00 inch. For vapor counters at the same pressure, the corresponding threshold would be several thousand volts.

The length of plateau decreased as the threshold decreased but the ratio of plateau length to threshold voltage was roughly the same as is ordinarily obtained with higher-voltage counters. The slope of plateau (Figure 7) was generally 15 to 25 percent per hundred volts in simple mixtures of a rare gas and a halogen. In admixtures of argon plus chlorine to the vehicular gas, neon, the plateau slopes were considerably reduced, as shown in Figure 8. For Figures 7 and 8, the

ordinate bears no relation to the wire size shown on the curves, the relative spacing of the curves being arbitrarily determined for ease of presentation. Counters made with 0.25 mm of a 4:1 argon-to-chlorine admixture in 20 cm Hg pressure of neon yielded thresholds at about 260 volts with plateaus that did not slope more than a few hundredths of a percent per volt, for 60 volts above threshold.

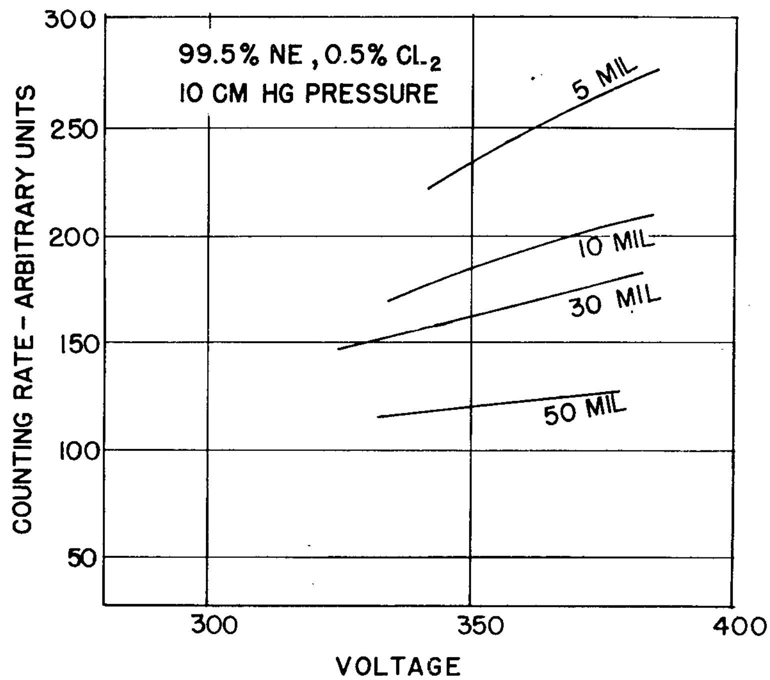

Fig. 7 - Plateaus of Neon-Chlorine Mixtures with Different Anode Diameters and Cathode Diameter of 2 cm

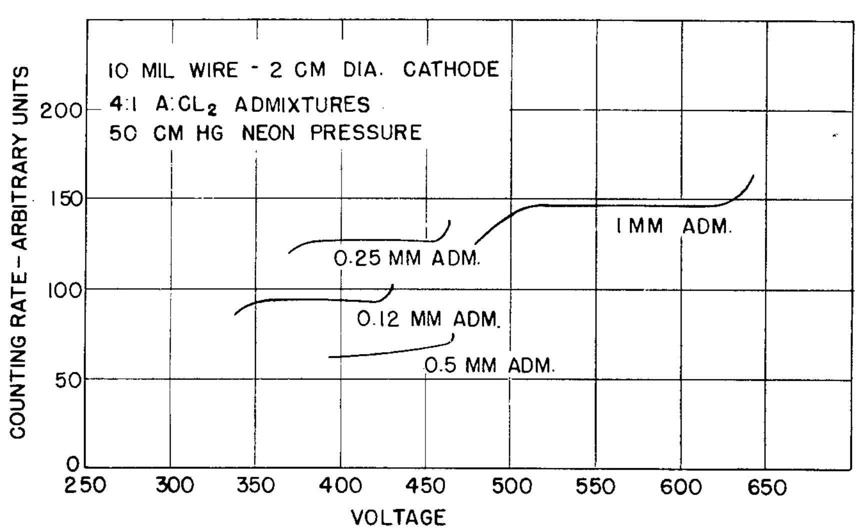

Fig. 8 - Plateaus of Counters Made with Various Argon-Chlorine Admixtures

EFFICIENCY, LIFE, AND TEMPERATURE COEFFICIENT

In response to gamma rays, the counting rates obtained with the halogen admixtures were very nearly the same as those obtained with the familiar argon-alcohol fillings. When the rare-gas-halogen type of counter was used in a cosmic ray coincidence telescope, its efficiency was close to 100 percent.

A double-cathode counter experiment** was performed with the rare-gas halogen mixtures. Although the cathode separation was one-half inch, every discharge spread across the gap, indicating that the propagation of the discharge was accomplished by photo emission from the cathode. The absence of any observed time delays between initiation of the discharge in one section and its spread to the other section, indicated that negative ion formation was inappreciable.

Self-quenching Geiger counters employing polyatomic vapors have limited lives because of the decomposition of vapor molecules in the discharge. The number of molecules decomposed in each discharge depends on the overvoltage. Operating a typical counter in the middle of the plateau will ordinarily yield a useful life of about 10^8 counts. At an overvoltage near the end of the plateau the counting life is much reduced, and exceeding the plateau limit for even a short time invariably destroys the useful properties of the counter. The counters with halogen admixture described here have no complex molecules to break down and cannot be harmed by subjecting them to extreme overvoltages leading to glow or arc discharges.

Most of the organic compounds used in counters introduce large temperature coefficients. Although the vapor constituent may be sufficient at room temperature, condensation at lower temperatures may shift the threshold or leave an insufficient amount to quench the discharge. Since the vapor pressure of chlorine used in the low-voltage counters is always less than one mm Hg pressure, no condensation is possible until the temperature is in the neighborhood of -100° C. A Ne-A-Cl_2 tube showed no measurable temperature coefficient between + 100° C and - 80° C.

DEADTIME AND PULSE-RISE TIME

The build-up time of the pulse is several times slower in halogen admixtures at the lowest voltages of operation than it is in organic-vapor-quenched tubes. At higher voltages, the build-up time of the two types are comparable.

The deadtime and recovery time of these counters is about the same as for conventional counters filled with the same rare gas plus an organic-vapor admixture.

* * *

**Liebson, S. H., Phys. Rev. 72; 602-608 (1947)

PRNC-4099-1-5-48-200

UNITED STATES GOVERNMENT

memorandum

Ser 059

DATE: 28 Sep 98

REPLY TO ATTN OF: Code 7600

SUBJECT: REVIEW OF "GEIGER COUNTER" REPORTS

TO: Codes 5227
1221.1 Cu 9/30/98

1. I have reviewed five unclassified NRL reports entitled, "Geiger Counter Technique (M-*1800)," "Geiger Counter Technique for High Counting Rates (H-2758*)," "Geiger Counter Tubes (ADB196664)," "Low Voltage Self-Quenching Geiger Counters (N-3189*)," and ("Sensitive Geiger-Muller Counters for Detection of Gamma Rays (M-1886).")
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2. I recommend that the "limited distribution" statements be removed from each report and be replaced with "unlimited distribution." Thank you.

HERBERT GURSKY
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